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Technical and Regulatory Requirements for Enhanced In Situ Bioremediation of Chlorinated Solvents in Groundwater (ISB-6)

EXECUTIVE SUMMARY

Enhanced *in situ* bioremediation (EISB) of chlorinated solvents in groundwater involves the input of an organic carbon source, nutrients, electron acceptors, and/or microbial cultures to stimulate degradation. EISB systems may be used to remediate high concentration areas within plumes or source areas, to help provide containment of a chlorinated solvent plume, or as part of a treatment train downgradient from a primary cleanup or containment system.

The major biological processes by which chlorinated solvent compounds degrade include anaerobic reductive dechlorination, aerobic cometabolism, and oxidation. Anaerobic reductive dechlorination involves the replacement of chlorine atoms in the chlorinated compound by hydrogen. An electron donor, either hydrogen gas or a precursor carbon compound, is necessary for the reduction to occur. Aerobic cometabolism involves the fortuitous degradation of chlorinated solvents by enzymes intended to metabolize compounds such as toluene, phenol, or methane. The organisms gain no benefit from the degradation, and may be harmed. Direct degradation of certain lesser chlorinated solvents can occur in either anaerobic or aerobic environments.

A key factor in the design of EISB systems is the mechanism of delivery of the various amendments to the targeted portion of the groundwater plume. Various types of delivery mechanisms have been used, including dual vertical well recirculation, horizontal well recirculation, combinations of well-infiltration trench recirculation, direct liquid amendment injection, gas amendment injection, and pass-through or reactive cell designs. Each of these may have advantages or disadvantages depending upon the major objective of the project and site conditions. For sites in which treatment of high concentration portions of a plume is the goal, systems with either dual wells or other arrangements may provide semi-closed loops which reduce downgradient flow of contaminants while providing biotreatment. For systems which are designed to reduce concentrations in portions of plumes downgradient from other remediation systems, some sort of pass-through system may be needed. These may include recirculation systems oriented at an angle to the natural hydraulic gradient, single-well recirculation systems, direct injection systems, or passive systems.

A variety of amendments may be added to EISB systems. Common carbon sources for anaerobic sites include lactic acid, sodium benzoate, methanol, and yeast extract. Common carbon sources for aerobic cometabolism sites are toluene, phenol, and methane. Most sites require nutrients, such as phosphate, nitrate, or potassium. Electron acceptors are added at some sites to promote cometabolism or direct oxidation of lesser chlorinated compounds, such as vinyl chloride. These can be added by gas injection or as a solid, such as magnesium peroxide. Naturally occurring or

engineered microorganisms with specific biodegradation capabilities can be added to promote aerobic cometabolism or (less commonly) anaerobic reductive dechlorination.

EISB systems may face significant regulatory issues that require careful attention. ITRC is seeking help from regulatory agencies to help resolve some of these issues. Multiple regulatory authorities may become involved in oversight and permitting. In particular, federal and state regulations regarding the movement, treatment, and reinjection of contaminated groundwater are confusing and subject to multiple interpretations. Recirculation and reinjection of contaminated groundwater in recirculation systems may be subject to RCRA hazardous waste and land disposal regulations. Class IV injections (hazardous waste injections into useable aquifers) for non-CERCLA and non-RCRA sites are prohibited by underground injection control (UIC) regulations.

There are potential solutions to these obstacles, including the use of Area of Contamination (AOC) and Corrective Action Management Units (CAMUs), CERCLA and RCRA permit waivers, and treatability variances. At present, there is no consensus on the best regulatory mechanism to allow reinjection to occur. It is therefore important to begin identifying permitting and other regulatory requirements and to communicate effectively with the public and stakeholder groups early in the process.

An EISB project should include a thorough initial site assessment, a laboratory treatability test, field pilot design, field pilot test, and scale-up design. The initial site assessment should accurately characterize the contaminant distribution in the area of the proposed system in both groundwater and source (if applicable). Natural attenuation parameters should be analyzed in both soil and groundwater. If necessary, the site assessment should include additional hydrogeologic study.

A laboratory treatability test should be employed at most sites. It should include either microcosm or column studies designed to show specific biodegradation mechanisms through mass determinations of parent and daughter products, and other metabolic products. The treatability test may also include direct microbial population information.

Based on the results of a successful laboratory treatability test, the field pilot should be designed to deliver amendments to the intended portion of the contaminated aquifer. All permitting and regulatory requirements should be identified and the permitting process should begin as soon as possible. The engineering design should incorporate a thorough understanding of the hydrogeology of the system. This normally includes modeling of groundwater flow, as well as transport and degradation of targeted compounds. A suitable field pilot site should be selected where the hydrogeology is fairly simple and well characterized.

Common problems encountered during operation of the field pilot include biofouling, and insufficient nutrient delivery. Biofouling can be reduced by well surging, pulsing of nutrients, and addition of high concentrations of certain electron donors or acceptors. A gradual startup of the system is recommended to determine the effective delivery rate and to reduce biofouling.

The ultimate success of the field pilot should be judged by a clearly defined loss of contaminant mass in the system, the laboratory and field evidence for specific appropriate microbial activity, and the correlation of contaminant loss with degradation parameters. Field evidence for cometabolism is more difficult than for anaerobic reductive dechlorination, and therefore cometabolism sites rely heavily on laboratory treatability studies.